Learning Progression-Based Teaching Strategies in Environmental Science: Teachers' Successes and Struggles in Implementation

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Abstract: The study presented here is part of a larger project to develop and use learning progression frameworks (NRC, 2007, 2012) to teach core strands of environmental science to secondary school students. We investigated 16 secondary science teachers' views and practices when implementing one of three learning progression-based environmental science units: biodiversity, the carbon cycle, or the water cycle. We asked: (1) How did teacher participants make sense of the learning progressions for secondary students' reasoning about biodiversity, the carbon cycle, or the water cycle? (2) How did these teachers understand teaching strategies aligned to learning progressions (LPTSs) and how they might use such strategies to elicit, respond to, and build on their students' ideas? (3) How did they actually implement these LPTSs in their classrooms? (4) How did the related professional development activities help or hinder teachers in their understanding and implementation of these teaching strategies? We began our qualitative analysis by purposively selecting four exemplary teacher participants from our sample of 16 teachers. We looked across these four teachers' interviews, responses to surveys and written reflections, and video records of their classroom instruction to identify successes and struggles in implementing LPTSs. We close with recommendations for ways to better align teaching strategies with learning progression ideas.

Introduction

In the US, learning progressions are an integral part of the new vision for K-12 science education (National Research Council [NRC], 2007, 2012; NGSS Lead States, 2013). A learning progression is a description of student thinking about a science or engineering practice, concept, or idea that increases in coherence and sophistication over a broad span of time. As Duschl, Maeng, and Sezen (2011) emphasized, what is often ignored in discussions about learning progressions is how they are inextricably intertwined with reform-based science instruction: Learning progressions "are crucially dependent on instructional practices if they are to occur. That is, traditional instruction does not enable most students to attain a good understanding of scientific frameworks and practices" (NRC, 2007, p. 219). However, few studies have examined how teachers understand and use learning progressions to implement reform-based science instruction (Gunckel, 2013; see Furtak, 2012, for an exception).

The study presented here investigates secondary science teachers' understanding and use of strategies aligned with learning progressions to teach core strands of environmental science. More specifically, as part of a long-term professional development and research effort, we investigated 16 secondary science teachers' understanding of learning progressions and learning progression-based teaching strategies (LPTSs), as well as their use of such strategies when implementing learning progression-based curricular units about biodiversity, the carbon cycle, or the water cycle. Our qualitative study was shaped by four questions: (1) How did teacher participants make sense of learning progressions focused on secondary students' reasoning about biodiversity, the carbon cycle, or the water cycle? (2) How did these teachers understand the LPTSs intended to elicit, respond to, and build on their students' ideas? (3) How did they actually implement the LPTSs in their classrooms? (4) Finally, how did the professional development activities help or hinder teachers in their understanding and implementation of these teaching strategies?

Conceptual Framework

To teach environmental science in reform-minded ways, teachers must attend to the scientifically accepted understandings students are expected to reach, the ideas their students hold, and the disciplinary discourse practices in which they engage. As such, our conceptual framework is constructed from three areas of scholarship: learning progressions, teachers' attention to students' ideas, and the language of science. We discuss each of these areas of scholarship in turn.

Learning Progressions

As stated above, learning progressions are descriptions of increasingly scientifically based and coherent ways of thinking about a science or engineering practice, concept, or idea (NRC, 2007, 2012; NGSS Lead States, 2013). They are anchored at the lower end by what we know about the concepts and reasoning of young children entering school and at the upper end by what disciplinary experts identify as appropriate scientific knowledge and practices. Intermediate levels are reasonably coherent networks of practices, ideas, and/or concepts that help to build a more coherent and scientifically accepted understanding. For example, Jin and Anderson (2012) proposed a four-level learning progression framework for how upper elementary through high school students use energy-related concepts in their accounts of carbon-transforming processes in socio-ecological systems (e.g., the creation, transformation, and oxidation of organic carbon).

As stated in the introduction, for learning progressions to help transform science education, they must be used to inform instruction (Duschl et al., 2011; NRC, 2007). Corcoran, Moshar, and Rogat (2009) suggested four features of learning progressions that can be used to guide adaptive instruction: (1) provide tighter ties between standards and the instruction that would enable students to meet them; (2) identify levels of progress so that teachers can better assess where their students are, when they need to intervene, and what kinds of intervention are appropriate; (3) inform the design of curricula so that materials are aligned with what students need to progress; and (4) form the basis for a fairer set of expectations for what students and teachers can accomplish during classroom instruction. The environmental science project examined here focused on features 2 and 3.

More specifically, participating teachers not only examined learning progression frameworks, but were provided instructional strategies and curricular materials aligned with learning progressions as well. Eight instructional strategies (LPTSs) aligned with learning progressions were identified (see Table 1 below). LPTSs help teachers operationalize learning progressions – so as to build instruction from their students' ideas and teach them environmental science concepts and principle-based reasoning (Gunckel, 2013). It is important to underscore that these LPTSs must be used in concert; one strategy implemented alone is not sufficient. For each of the three content strands of biodiversity, the carbon cycle, and the water cycle, a curricular unit, or teaching experiment, was also constructed to facilitate teachers' use of learning progressions in their instruction. Each teaching experiment (TE) includes activities, formative and summative assessments, and tools for reasoning to support students in moving along a four-level learning progression. (Teaching experiments are discussed in greater detail under Context.)

Table 1
Learning Progression-Based Teaching Strategies (LPTSs)

LPTS	Definition
1	Identify and focus instruction on important big ideas in the field of study.
2	Plan instruction based on student understanding of a given topic.
3	Develop and use formative assessments to guide selection of instructional strategies and sequences.
4	Support student learning through careful attention and response to student thinking during instruction and when assessing student work.
5	Engage students in guided or open inquiry with authentic events and experiences.
6	Engage students in developing increasingly complex principle- and evidence-based accounts of environmental processes in socio-ecological systems.
7	Link the target environmental science strand (biodiversity, the carbon cycle, or the water cycle) to real problems in the local context, anchoring students' learning in their culture and place.
8	Encourage engagement in citizenship practices, including constructing arguments and making decisions, related to socio-scientific issues.

Attending to Students' Ideas

To support students in learning science, teachers must plan lessons that build on students' current ideas, that challenge students to question these ideas, and that help them to develop more sophisticated understandings about scientific phenomena and practices (Hammer, 2001). For teachers, the obvious but necessary first step in attending to students' ideas is to encourage students to talk about their ideas (Gallas, 1995). Sherin, Jacobs, and Philipp (2011) termed this "noticing" students' thinking. A second step is being able to interpret these ideas once students have articulated them. If a teacher is to support students in their learning of science, she or he must not only have a firm grasp of science content and the ways scientists talk about science, but be able to understand students' talk and infer their ideas about science content from their talk as well (O'Connor & Michaels, 1993; Rosebery, Ogonowski, DiSchino, & Warren, 2010). A final step for teachers is to use students' ideas to inform their instructional decisions (Harlow, 2010; Otero & Nathan, 2008).

Studies have reported mixed success in teacher attention to students' ideas. For example, Otero and Nathan (2008) found that even after eliciting and valuing students' ideas, many preservice teachers in their study did not use these ideas to inform their next steps in instruction. As a second example, Harlow (2007, 2010) investigated the views and practices of experienced elementary teachers who participated in a model-based professional development project. She found that some teachers tried to implement model-based activities without eliciting their own students' ideas or without designing appropriate follow-up investigations to test ideas students proposed. Others, however, were able to appropriately modify their instruction to challenge and build from their students' ideas. As a third example, Furtak (2012) studied the use of a learning progression for natural selection to support teachers' implementation of formative assessments. During formative assessment conversations with their students, teachers often identified and interpreted students' ideas; however, they were more likely to repeat or clarify what students said rather than make explicit inferences about students' ideas. Further, in those instances where explicit inferences were made, some teachers helped students think through their own ideas while others told students their ideas were wrong.

The Centrality of Discourse in the Teaching and Learning of Science

Learning science involves learning the language unique to science disciplines and how to use that language to express ideas and build understanding (Brown, Collins, & Duguid, 1989; Lemke, 1990). This view of language as central to the learning of science emerges from studies of scientists as communities: Scientists interact with one another using specific oral and written discourse styles (Bazerman, 1988; Latour & Woolgar, 1979; Yore, Florence, Pearson, & Weaver, 2006). This view of the centrality of language is also found in descriptions of current reform-based science and engineering practices (NRC, 2007, 2012; NGSS Lead States, 2013). The new standards in science explicitly call for teachers to develop students' language and literacy in and through engagement in disciplinary core practices, concepts, and texts (Bunch, 2013). Quinn, Lee, and Valdés (2012) argued that four of the eight science and engineering practices are particularly discourse-intensive: developing and using models; constructing explanations (for science) and designing solutions (for engineering); engaging in argument from evidence; and obtaining, evaluating, and communicating information. These practices, they elaborated, can be understood as "exercise[s] in the coordination of language and experience and thus another rich language learning opportunity" (pp. 4-5).

Science teachers, then, must move away from the narrow teaching of academic language in science as the review of vocabulary terms or the means to communicate the content one has learned (Bunch, 2013). For example, Bruna, Vann, and Escudero (2007) found that a teacher's understanding of academic language development as vocabulary led to watered-down science discourse in an ELL classroom. As a second example, Halliday (1993) asserted that a teacher's focus on vocabulary alone will not assist students in learning to understand and use the language of science: "Vocabulary is much more obvious, and easier to talk about, than grammar . . . .

[However,] the problems with technical terminology usually arise not from the technical terms themselves but from the complex relationships they have with one another" (p. 71). As a third example, Rowe (1974), and more recently, the NRC (2007) encouraged science teachers to replace the rapid-fire exchange of questions and answers with conversations about natural phenomena – where students share their own ideas, respond to others, and collectively engage in scientific reasoning. Indeed, Michaels and O'Connor (2012) created a *Talk Science Primer* that outlines four goals, three talk formats, and nine talk moves teachers can use to facilitate productive classrooms discussions. In short, science teachers must present language as a mediator of the teaching and learning process and must support students' development of sense-making talk across their everyday and scientific languages, their engagement in science and engineering practices, and their oral and written communication.

Research Methods

Context: Professional Development and Curriculum Materials

Pathways, a five-year research and professional development effort, served as the site of our study. Begun in 2008, Pathways was a partnership among four environmental science research institutes situated in diverse geographic, demographic, and institutional settings (East Coast, Great Lakes, Mountain, and West Coast). Pathways attempted to promote environmental science literacy in three ways: (1) to develop biodiversity, carbon cycle, and water cycle learning progression frameworks for students from upper elementary school through college; (2) to develop curriculum materials and assessments aligned with each of these frameworks; and (3) to help secondary science teachers learn how to understand and use these learning progression frameworks and their associated supporting materials to teach environmental science in reform-minded ways. The study presented here was conducted during the 2012-2013 academic year, Pathways' fifth and final year of implementation.

Professional development. At each of the four professional development sites, secondary science teachers attended annual summer institutes and periodic follow-up meetings during the academic year. The number of participating teachers varied at each site and within each site year to year. Over the five years of the Pathways PD project, there were 336 secondary science teachers who participated. The professional development team at each site was composed of scientists, experienced teachers, science educators, postdoctoral scholars, and graduate students. Each team decided on particular content to discuss and activities to complete. However, all sites discussed learning progressions; engaged teachers in sample activities from the three TEs; presented findings from analyses of students' assessments; and provided support (e.g., equipment, additional information, and supplementary materials) during actual implementation.

Curriculum (TEs). As stated above, part of Pathways professional development efforts centered on the construction and implementation of three curricular TEs: biodiversity, the carbon cycle, and the water cycle. Each TE provides teachers with a four-level learning progression – a series of carefully orchestrated lessons, and concrete strategies and resources – to use in concert to move students to more sophisticated levels of understanding. The four levels of these learning progressions are defined in Table 2 below from most to least sophisticated.

Table 2
Learning Progression Levels

LP Level	Title	Description
4	Scientific Model-Based Accounts	Students apply fundamental principles, such as conservation of matter and energy and genetic continuity, to phenomena at multiple scales in space and time (generally consistent with current national

		standards).
3	Incomplete School Science Accounts	Students show awareness of important scientific principles and of models at smaller and larger scales, but they have difficulty connecting accounts at different scales and applying principles consistently.
2	Elaborated Force-Dynamic Accounts with Mechanisms	Students continue to focus on actors, enablers, and natural tendencies of inanimate materials. However, they add detail and complexity, especially at larger and smaller scales.
1	Simple Force-Dynamic Accounts	Students focus on actors, enablers, and natural tendencies of inanimate materials, using relatively short time frames and macroscopic scale phenomena.

Biodiversity. The TE, *Biodiversity: Diversity in a Leaf Pack,* engages students in the central question of why communities are assembled in a particular way. Using the freshwater stream ecosystem as the context for their learning, students explore the following additional questions: What lives in leaves in a stream? What is biodiversity? What lives in leaf packs? Who eats whom? How are organisms related? It highlights three key principles that are essential for reasoning about biodiversity: richness, evenness, and abundance. The Biotic/Abiotic Interactions Reasoning Tool helps student identify the biotic and abiotic factors of an ecosystem and predict how a disturbance will affect these factors. Thirteen formative assessments are included in the TE as well. In total, the Biodiversity TE includes 13 lessons. Its purpose is to increase students' ability to apply biodiversity principles to their observations and reasoning about the natural world, specifically: (1) to recognize that macroinvertebrate and microorganism diversity exists; (2) to classify organisms based on similarities and differences in morphology, biotic and abiotic requirements, and dispersal ability; (3) to understand major factors that structure biological communities; (4) to understand that organisms' activities influence the abiotic environment and to predict how a change in the population of a given organism would impact the abiotic environment and, in turn, other biota; and (5) to understand the components of biodiversity and why biodiversity is important for ecosystem functioning.

The Carbon Cycle. The TE, *Plant Growth and Gas Exchange,* engages students in exploring two questions related to the carbon cycle: Where does dry plant matter come from? What is the main component of plant matter? The TE emphasizes two science practices – inquiry, or investigating practices, and accounts, or explaining and predicting practices – and three key principles that are essential for reasoning about environmental processes – scale, matter, and energy. Two tools for reasoning support students' thinking about the processes of scale, matter, and energy by providing visual cues for both the teacher and the learner: the Powers of 10 Tool and the Matter and Energy Process Tool. There are also six suggested formative checks (or suggested ways to formatively assess students), one embedded assessment quiz, and one suggested summative assessment. In total, the TE includes 11 lessons. By the unit's end, students are expected to connect key biogeochemical processes in socio-ecological systems at multiple scales, including cellular and organismal metabolism, ecosystem energetics and carbon cycling, carbon sequestration, and combustion of fossil fuels. They are to understand the processes that create organic carbon (e.g., photosynthesis); transform organic carbon (e.g., biosynthesis, digestion, food webs, carbon sequestration); and oxidize organic carbon (e.g., cellular respiration, combustion).

The Water Cycle. The TE, *School Water Pathways,* asks students to explore the following research question: How much water falls on our schoolyard during a year and where does it go? Students engage in scientific inquiry practices as they study the water cycle as it occurs at their school. Two tools for reasoning support students' thinking in this TE. The Pathways Tool helps students trace water along multiple and branching pathways, as it flows to and away from one particular location. The Drivers and Constraints Tool facilitates students' identification of the processes that move water from one location to another (e.g., evaporation, infiltration, etc.), as well as the driving forces (e.g., gravity) and constraining factors (e.g., topography, permeability) of water flow. Four formative assessments are included in this TE as well. In total, the Water TE includes 4 lessons spanning a minimum of 6 days. Ultimately, students are expected to learn four central features of water movement in socio-ecological systems: (1) Water that falls on the surface of the Earth is driven by gravity and may follow multiple pathways governed by multiple processes. (2) The processes and pathways that water follows depend on many factors. (3) The volume of water that follows all pathways is equal to the volume of water that falls on a set area. (4) The water cycle takes place all around us and we are part of it.

Participants and Researchers

Sixteen secondary science teachers participated in this study (see Table 3 below). These case study teachers constituted approximately 10% of the 160 teachers who participated in the larger Pathways project during 2012-2013. They included four teachers from each of the four PD sites: West Coast, Mountain, Great Lakes, and East Coast. We recruited teachers who project staff considered exemplary: Teachers who had regularly attended professional development meetings and had thoughtfully implemented Pathways curricular units in previous years. We selected an equal number of middle school and high school teachers. We also attempted to capture a similar number of instances of implementation of each of our three TEs: Six teacher participants implemented the water cycle; six, biodiversity; and four, the carbon cycle. We collected data in one classroom of each case study teacher. We note that many case study teachers implemented more than one TE, as well as implemented a given TE in more than one classroom. In these cases, the researchers and teacher decided together which TE to investigate and in which classroom to collect data.

Table 3
Case Study Teachers' Demographic Information

Teacher	Region	Grade Band	Gender	Ethnicity	SES	Year Started PD	TIR/ RET	TE Implemented
Ms. Z	West Coast	Middle	Female	White	Middle Class	2012		Biodiversity
Ms. L	West Coast	Middle	Female	White	Middle Class	2011		Water
Ms. E	West Coast	Middle	Female	German/English/ Danish/Welsh/ Scottish	Lower Middle Class	2011		Carbon
Mr. K	West Coast	Middle	Male	White/ European	Lower Middle Class	2011		Water
Ms. V	Mountain	High	Female	White/Caucasian	Middle Class	2011	TIR, RET	Water
Mr. J	Mountain	Middle	Male	White	Middle Class	2011	TIR	Water
Ms. T	Mountain	Middle	Female	White	Middle Class	2008		Biodiversity
Ms. S	Mountain	Middle	Female	White	Borderline Poverty	2010	RET	Carbon
Ms. M	East Coast	High	Female	Asian	Working Class	2010		Biodiversity
Mr. A	East Coast	High	Male	Indian	Middle Class	2009	RET	Carbon
Ms. P	East Coast	High	Female	White	Middle Class	2012		Water
Mr. B	East Coast	High	Male	White	Middle Class	2011	RET	Biodiversity
Ms. F	Great Lakes	High	Female	White	Middle Class Poor	2007	RET	Biodiversity
Mr. D	Great Lakes	Middle	Male	White	Middle Class	2007		Water
Mr. G	Great Lakes	High	Male	White/Caucasian /German/French Canadian	Lower Middle Class	2010	RET	Carbon
Ms. R	Great Lakes	High	Female	White	Middle Class	2010		Biodiversity

Note: Teachers' ethnicity and SES are self-reported. TIR were "Teachers In Residence" who worked fulltime or part-time for a year on the professional development project. RET were teachers who participated in a "Research Experience for Teachers": They conducted research in science or science education. Target teachers are highlighted.

From this purposeful sample of 16 case study teachers, we identified four target teachers (see Table 4 below). Target teachers were selected after all data had been collected and video records of classroom instruction had been reviewed. We used three criteria in our selection process: (1) We included one teacher from each of the four sites. (2) From review of video records, we selected those teachers with a substantial number of classroom discussions (this is discussed further below). (3) We ensured that all three TEs were included. To clarify, while we collected the same types of data from all 16 case study teachers, for our analysis, we narrowed our examination to these four target teachers.

Table 4
Target Teachers' School and Classroom Information

Target Teacher	**School Context**	**Community Context**	**TE Taught**	**Class Videotaped**			
				Title	**Length (min)**	**% female and male students**	**% ethnicities of students**
Ms. P	Private High School	Suburban, large	Water Cycle	12^{th} Grade Science Elective	60 (4 days) 70 (1 day)	100% female	100% European American
Ms. R	Public High School	Rural, distant	Biodiversity	9^{th} Grade Introductory Chemistry and Biology	90	38% female 62% male	5% African American 90% European American 5% Latina/o
Mr. J	Public Middle School	Town*	Water Cycle	8^{th} Grade Environmental Science Elective	90	50% female 50% male	10% Asian American 65% European American 15% Latina/o 10% Other
Ms. E	Public Middle School	Urban, small	Carbon Cycle	7^{th} Grade Honors Life Science	45	50% female 50% male	50% European American 50% Latina/o

*The category of town falls between the categories of suburban and rural.

Researchers included scientists, science educators, postdoctoral scholars, and graduate students. They varied across their participation in the professional development and research efforts. Four of the nine conducted Pathways professional development activities and designed curricular materials. Seven engaged in the creation of instruments and in the collection of data. All nine organized and analyzed the data presented here.

Data Collection and Analysis

We collected four types of data from each of our 16 case study teacher participants during the 2012-2013 academic year. One type of data was interviews. We individually interviewed each teacher participant three to four times over the course of the academic year, as well as conducted one focus group interview with a subset of each teacher's students. Interviews were audio recorded; each lasted on average one hour. Our second type of data was classroom observations. We observed each teacher teaching one class period during five consecutive days of instruction during the TE. We both wrote field notes on a classroom observation checklist and used two video cameras to record both whole class and small group interactions. As our third data type, we asked teacher participants to complete a number of writing assignments: a unit content test, two written reflections about their understanding and implementation of learning progression frameworks and learning progression-based teaching strategies, a feedback form at the end of their TE implementation, and a second survey at the end of the year about their experiences in the project. We also asked students in the one classroom we recorded to complete a survey. Fourth and finally, we collected samples of work completed by students in the recorded classroom.

Teacher and student interviews were transcribed by either researchers or by a professional service. All were checked by researchers for accuracy. Transcripts of teacher interviews, video records of classroom instruction, and teachers' written responses were then qualitatively analyzed to answer our four research questions posed above. More specifically, to answer research questions 1, 2, and 4, we constructed separate sets of a priori descriptive codes

(Saldana, 2013) to use in coding teachers' interview transcripts, written reflections, TE feedback forms, and end-of-year surveys.

To answer research question 3 on teachers' actual implementation of LPTSs, we analyzed the video records of classroom instruction. We first divided all lessons for our four target teachers into smaller instructional segments. We next identified teacher-student discussions within each lesson segment and determined whether each was productive or unproductive. Further, for all segments that included at least one productive discussion, we coded for teachers' implementation of the eight LPTSs discussed in our conceptual framework above. Our purpose in doing so was to map the sequence and frequency of LPTSs used by teachers to productively engage their students in talking and thinking about environmental science concepts. We provide definitions of the terms lesson segments, discussions, and productive/unproductive in Table 5 below. We clarify for readers that while we borrowed the notion of a productive discussion from Michaels and O'Connor (2012), the definition of a productive discussion is our own.

Table 5
Analytic Cycles to Answer Question 3: Teachers' Use of LPTSs in Classroom Instruction

Analytic Cycle	**Unit of Analysis**	**Instructional Code**	**Definition**
1	Lesson	Lesson Segment	A part of a lesson delineated by topic and purpose. (For example, a teacher might introduce a process tool; the students might fill it out individually, discuss their answers in a small group, and share out to the rest of the class; and then the teacher connects the process tool to one of the TE's big ideas.)
		Discussion	A part of a lesson segment where a teacher interacts with one or more students. Must include the following: (a) The interaction is about content (not about attendance, discipline, etc.). (b) The interaction includes at least three turns of speech.
		Productive	Used to describe a subset of discussions. Discussion must include the following: • Ties to the TE in terms of content and/or LPTSs. • Typically encompasses more than just asking a question and eliciting students' ideas. A teacher asks: Why? How do you know? What does anyone else think? • Connects/links between at least two concepts or two dimensions of a concept.

			• Two parts of a productive discussion can be separated by time.
2	Lesson Segments with Productive Discussions	LPTS 1	Identify and focus instruction on important big ideas in the field of study.
		LPTS 2	Plan instruction based on student understanding of a given topic.
		LPTS 3	Develop and use formative assessments to guide selection of instructional strategies and sequences.
		LPTS 4	Support student learning through careful attention and response to student thinking during instruction and when assessing student work.
		LPTS 5	Engage students in guided or open inquiry with authentic events and experiences.
		LPTS 6	Engage students in developing increasingly complex, principle-based, and evidence-based accounts of environmental processes in socio-ecological systems.
		LPTS 7	Link the target environmental science strand (biodiversity, the carbon cycle, or the water cycle) to real problems in the local context, anchoring students' learning in their culture and place.
		LPTS 8	Encourage engagement in citizenship practices, including constructing arguments and making decisions, related to socio-scientific issues.

Findings

To reiterate, the purpose of our study was to better understand the ways learning progression frameworks can inform science teachers' instruction. Our findings are presented in order of our research questions: We examine (1) teachers' understanding of learning progressions, (2) their views of instructional strategies aligned to learning progression frameworks, (3) their implementation of LPTSs when teaching environmental science, and (4) how the professional development supported or constrained their classroom practices.

Finding Set 1: Teachers' Views of Learning Progression Frameworks

We drew from interviews and written responses to explore teachers' understanding of learning progression frameworks. Teachers were provided repeated, explicit opportunities to articulate their definition of and experiences with learning progressions. In their first interview, for example, each was asked to define a learning progression, to give a specific example, to explain how to move students from one level of a progression to another, and to discuss how their understanding of learning progressions helped them to implement the observed curricular unit. We examined two dimensions of their understanding of learning progressions: (1) their general definition and (2) those aspects emphasized. We found that our four target teachers spoke about learning progressions in similar ways.

Definitions of a learning progression. We found that all four of our target teacher participants provided similar definitions of a learning progression – as increasingly sophisticated levels of understanding of a science concept or idea. For example, Mr. J described a learning progression as movement up a ladder to deep and connected understanding:

> [A] learning progression is a continuum of understanding related to a concept or a scientific idea. And the progression moves from superficial knowledge, to connections, to driving forces. As we move up the ladder [of the progression], a student or a learner could explain not only the concept, but the driving forces [and] multiple scales of magnitude, or scale it up, scale it back. And potentially, if they really understand the topic, can apply it in a context outside of that – different than what they've experienced. (Interview 4)

Common emphases across learning progression descriptions. We also identified three themes, or emphases, across our target teachers' descriptions of learning progression frameworks. One emphasis articulated by all four teachers was the importance of moving students beyond superficial, school science understandings of phenomena. Ms. E, for example, focused her efforts on determining the depth and sophistication of her students' thinking in relation to the learning progression framework.

> [A learning progression] helps me look at the sophistication of their [my students'] understanding. Because what students will tend to do a lot, if they don't understand, is they just write a whole bunch of stuff. . . . It's [either] so fuzzy that you really can't tell if they understand it because they don't use any specific terms. Or the terms they use are

> jumbled together in a nonsensical fashion. So learning progressions I think help us see the complexities possible and then where the students are at in this complexity. . . . I think it [a learning progression] helps us make sure we understand our field well and understand what it means to have a sophisticated understanding in our field. (Interview 4)

Ms. E clarified that she viewed a sophisticated understanding as one held by a scientist (Level 4 Scientific Model-Based Accounts) rather than as one held by an educator (Level 3 School Science):

> It's more like how a scientist would judge things versus how an educator now judges things with students. And so if we're trying to bring [students] that close to what a scientist [understands] – scientific proficiency from a scientist's point of view rather than scientific proficiency from the educator's point of view. (Interview 4)

A second theme was also shared across all four teachers: When reaching the final level of a learning progression, students should be able to apply a concept to related areas and/or to the real world. For example, in her initial interview, Ms. R explained that the final level of the biodiversity learning progression included application of the big ideas of biodiversity to a new system:

> And their [the students'] final step [in the learning progression] would be [being] able to apply it to all systems and totally understanding it and being able to give examples. Given new information about some imaginary ecosystem on Mars, [for example], and being able to look at that and explain what the biotic and abiotic factors are, how if you change one [factor], the effect on the food web and all the biodiversity. . . . The final level is being able to apply it to totally new systems. (Interview 1)

A third theme related to learning progressions was identified by three of our four target teachers, all except for Ms. P. This theme was attention to key scientific constructs articulated in the Pathways TEs. For example, in his definition of a learning progression presented above, Mr. J included several key constructs emphasized in the Water Cycle TE: driving forces and different scales of magnitude. As a second example, in her description of a specific example of a learning progression also presented above, Ms. R included the key constructs of ecosystem, biotic and abiotic factors, interactions, and biodiversity central to the Biodiversity TE. As a third example, Ms. E underscored the use of learning progressions not only to deepen students' understanding of science content, but their academic language proficiency as well: "It's also a level of English almost, as they're acquiring English and learning academic vocabulary along with their understanding [of content]" (Interview 4).

Finding Set 2: Teachers' Views of Instructional Strategies Aligned to Learning Progression Frameworks

To answer our second research question, we investigated two dimensions of teachers' views of the eight LPTSs: (1) which LPTSs teachers implemented regularly during the lessons observed, and (2) how they understood LPTSs to help move students to higher learning progression levels. As with our examination of target teachers' understanding of learning progressions, we found substantial overlap in their descriptions of how they used the LPTSs in their instruction.

LPTSs teachers reported they regularly implemented. Along the first dimension, when asked explicitly to identify those LPTSs implemented during the TE, each target teacher participant thought she or he implemented most of the eight strategies to some extent (see Table 6 below). For example, Ms. P stated that she implemented almost all of the LPTSs during the Water Cycle TE: LPTSs 1, 2, 3, 4, 5, and 7. She did not regularly encourage principle- and evidence-based reasoning, LPTS 6, or citizen-based decision-making, LPTS 8. Several strategies she emphasized, LPTS 2 and LPTS 3, were tied to student thinking.

> I would say what pops out is probably [LPTS] 2 [on planning instruction based on student understanding] and [LPTS] 3 [on formative assessment]. First, looking at the formative assessments, using that to guide the selection of strategies and sequences, and then based on those formative assessments, figuring out where the students are coming [from], so . . . [as] to get all of the different groups on the same page, to get to the big idea [LPTS 1]. (Interview 2)

Additional strategies she regularly implemented were LPTS 1 on big ideas, mentioned in the excerpt above, and LPTS 5 on inquiry.

> For the big ideas I think that's kind of the main points of the unit that we're covering. So for water it was the steps of the water cycle, it was the water pathways, and how water flows through those pathways. For the authentic events and experiences I think, for me, that's in the inquiry. That's the hands-on where they're doing something in the classroom themselves. They're not just listening to me talk. So I think doing that helps to reinforce those big ideas and they're not going to remember every detail. (Interview 4)

In describing his implementation of the Water Cycle TE, Mr. J explained that he used all of the LPTSs to some extent. He thought LPTSs 1, 2, 3, and 4 particularly central to his instruction. For example, he discussed his consistent, but partial use of LPTS 3, formative assessments:

> Formative assessments in the sense of as they're doing [them], and that's [LPTS] number 3. . . . That tells me something [about their prior knowledge]. But as far as taking it [the completed student assessment] and re-strategizing for the next day, not quite as much. (Interview 2)

As a second example, he noted that he elicited and responded to students' ideas, LPTS 4, even when collecting data out in the field:

> [LPTS] Number 4, support student learning through careful attention, response to student thinking through discourse and comments on student work, I do quite a bit of that. I try to do that even when they're out in the field, just some probing questions for them to explore more. (Interview 2)

Ms. E. stated that she incorporated seven of the eight LPTSs in her two-week implementation of the Carbon Cycle TE – all except for LPTS 8 on engagement in science-based citizenship practices. Ms. E considered LPTSs 1, 3, 4, 5, and 6 those strategies most central to the Carbon Cycle TE. As one example, Ms. E emphasized, "Inquiry, that's one of the strengths of this [TE]. [LPTS] number 5 is one of the strengths of this learning experience." Interesting, unlike Ms. P above, Ms. E drew a clear distinction between LPTS 2 on planning instruction from students' thinking and LPTS 3 on using formative assessments to guide instruction: She thought that the TE did the former while she implemented the latter.

> [LPTS 2], anticipated level of [student] understanding [of a given topic], . . . the unit itself did that. I don't know that I did it. [LPTS 3], formative assessments, yes, I did look at their formative assessments. . . . And they were useful." (Interview 2)

Finally, like Ms. R below, Ms. E noted that she implemented LPTS 8 in other units in the course.

Ms. R identified LPTSs 2, 4, 5, 6, and 7 as strategies she regularly implemented during the Biodiversity TE. Ms. R clarified that she attended and responded to student thinking, LPTS 4, but did so only during class time. She did not provide students feedback on their written work, considering herself "grossly negligent" in this respect. Ms. R also planned to highlight LPTS 8, citizenship practices, throughout the rest of the semester; she thought this strategy central to her overall course (Interview 2 and 4). Further, she noted that she did not "hit" much on LPTS 1, focusing instruction on big ideas, and tended to make instructional decisions based on students' responses in class, LPTS 4, rather than from formative assessments, LPTS 3 (Interview 2 and 4).

Table 6
LPTSs Teachers Reported Regularly Implementing

Teacher	LPTS 1 Big Ideas	LPTS 2 Planning	LPTS 3 Formative Assessments	LPTS 4 Attending to Ideas	LPTS 5 Inquiry	LPTS 6 Reasoning	LPTS 7 Local Context	LPTS 8 Citizenship
Ms. P (Water Cycle)	X	X	X	X	X		X	
Ms. R (Biodiversity)		X		X	X	X	X	X
Mr. J (Water Cycle)	X	X	X	X	X	X	X	X
Ms. E (Carbon Cycle)	X	X	X	X	X	X	X	X

LPTSs teachers identified as central to moving students along a progression.

Teacher participants spoke in detail about how to move their students from one level of a learning progression to the next. In order to move students, teachers generally agreed that four LPTSs were essential: LPTS 1, LPTS 4, LPTS 5, and LPTS 6. We clarify that individual teachers identified additional LPTSs as integral to their own instruction and that several discussed strategies, like differentiation, not encompassed by the eight LPTSs.

More specifically, three of our four target teacher participants, all but Ms. R, identified LPTS 1, a focus on big ideas, as helping to move students along a learning progression. Indeed, Ms. P, Mr. J, and Ms. E agreed that attention to big ideas was one of two LPTSs they considered most central to their instruction. Ms. E noted that she wrote the main questions of the TE and the subquestions of that day's lesson on a designated white board. She saw the big ideas as providing connections for students, as helping them to better understand and better remember science concepts: "It's more connected. We can teach it for a longer period of time so that students have a greater chance of learning, because you have a kind of basis in place." She later clarified that she thought the extended time to explore a few key ideas in depth important: "We don't always teach this way, where we have a large idea and we're exploring different parts of it each day for quite a while" (Interview 3).

All four teachers pointed to LPTS 4, attending and responding to students' ideas, as a key strategy they implemented to help students move along a progression. All four thought class discussions essential for eliciting and providing feedback on students' ideas; fewer provided students feedback on their written work. For example, Ms. E identified LPTS 4 as one of two key LPTSs she regularly implemented. As a second example, Ms. R contrasted her infrequent use of LPTS 3, formative assessments, with her regular implementation of LPTS 4: "So I would say probably more than using the formative assessments, [LPTS 3], I'd pay attention to the response and the student thinking during the classroom and focus on what needs to be done [to further their understanding in that context]" (Interview 4). As a third example, Mr. J identified LPTS 4 as one of his strengths as a teacher: "I think one of my strengths as an educator is [LPTS] number four, where you're really listening to what they're saying and moving the conversation or the direction of the learning where it needs to go" (Interview 4).

Further, all four teachers mentioned LPTS 5, engaging in learning through inquiry, as vital for student movement. Both Ms. P and Ms. R identified LPTS 5 as one of two strategies they thought most central to their instruction. Ms. P, for example, repeatedly highlighted the importance of instruction (see again, NRC, 2007) in moving students "up to the next level" of the progression – "doing some kind of experiment or hands-on activity to really delve into the learning" (Interview 1). Ms. R agreed that engagement in activities was instrumental in facilitating student learning:

> We're doing a lab and I have them write on the board or I write up what the question is. . . . We talk about it as a class. We work through and identify the independent, dependent variables, what we're changing, and then getting them to predict what they think the result will be. And they have to explain why they think that. . . . They have to really think about why they are making that prediction. And then we do the experiment, collect the data, and then I spend a lot of time teaching them to evaluate the data, [to] see if their hypothesis is supported or contradicted, and then what that means. . . They have to take a step back and say, "Why did these results make sense?" And then [we] talk about what they would do next, what these results would allow them to test further if they were interested, and what possibly they could have done wrong. So I think the biggest challenge in teaching like this is getting the students to understand that they're doing the inquiry-based labs to strengthen their understanding of science that will allow them to understand the material. . . to [help them] understand that everything we do [in an investigation] is to get them to a greater understanding. (Interview 4)

Finally, three of the four teachers, all but Ms. P, underscored the importance of engaging students in reasoning, LPTS 6. Mr. J argued that engagement in reasoning, particularly engaging in reasoning from evidence, was important in moving students up higher levels of a learning progression. He thought engagement in inquiry more crucial for students in the lower levels.

> I think on the lower levels of learning progressions, students need to be engaged in the learning. They need to be doing something where they're seeing it, experiencing it. . . . I think when you get up to the upper levels, it's more of setting the stage for asking the question, "Why? Why? Why? Why?" And then have those students making a claim and really critiquing – challenging them to provide evidence to support that claim. I think in school we play school and you say, "Why?" "Because that's the way th[at] nature works, because there's heat added." Well, then keep asking, "Why? Well, why does – what role does heat have into that? What drives that?" (Interview 1)

Finding Set 3: Teachers' Classroom Implementation of LPTSs

We began our examination of teachers' actual implementation of LPTSs by identifying lesson segments that included productive discussions between teacher and students. Our purpose in doing so was to narrow our investigation to those segments that provided rich examples of teachers eliciting and building from their students' ideas, segments that we investigated further for use of specific LPTSs (see again Table 5). We found relative consistency across teachers in the percentage of lesson segments which included one or more productive discussions: 50% of segments in Ms. P's classroom included one or more productive discussions, 43% in Ms. R's classroom, 52% in Mr. J's classroom, and 67% in Ms. E's classroom. (See Figure 1 below.)

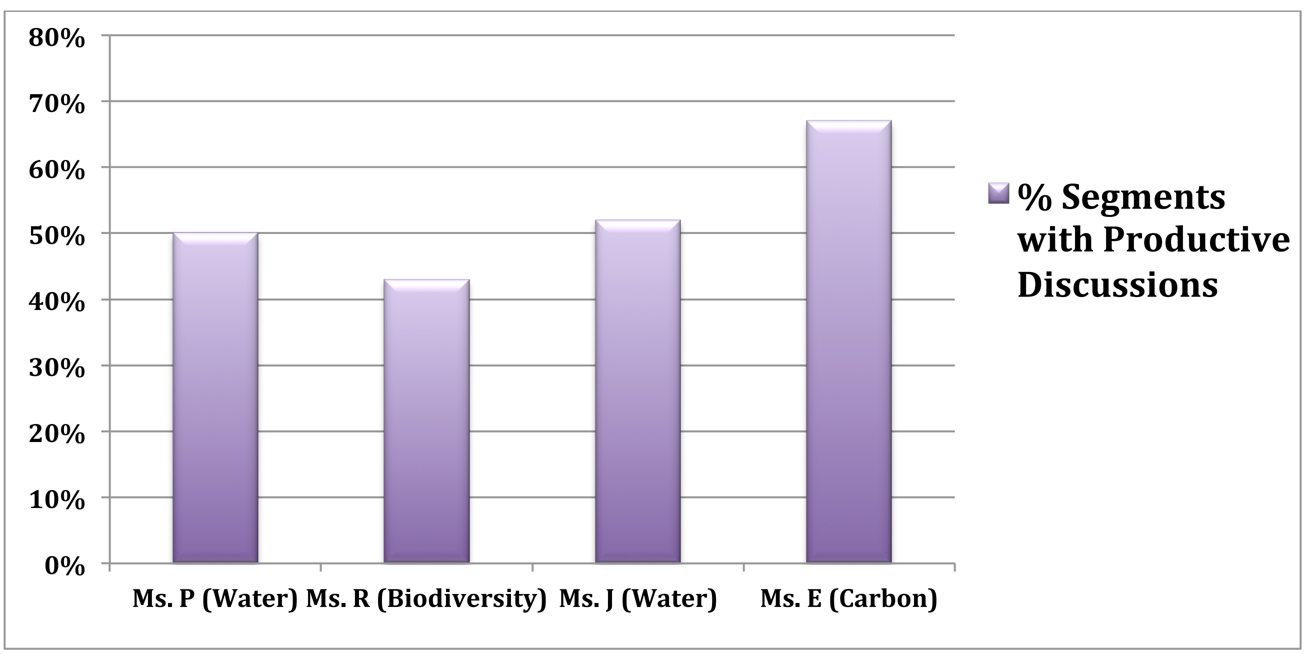

Figure 1. Percentage of lesson segments with productive discussions for five videotaped lessons for each target teacher. Note that these are percentages, not individual counts.

We then documented the specific LPTSs target teachers used during those lesson segments that included one or more productive discussions. Again, we decided to restrict our investigation of teachers' LPTSs implementation to lesson segments that included productive teacher-student conversations because of arguments put forth in our conceptual framework above: the centrality of discourse in the teaching and learning of science. We clarify that we examined strategies implemented across entire segments with productive discussions, not simply during productive discussions themselves. We note that a given teacher sometimes implemented one LPTS at a time, for example, LPTS 4 on attending and responding to students' ideas, and sometimes implemented two or more LPTSs simultaneously, for example, LPTS 5 on inquiry and LPTS 7 on local context. We also remind readers that we captured only five days of implementation of a TE; some of the differences between reported and recorded practices can be explained by the limitations of our sampling process. Across our four target teachers, we identified several similarities and differences in their classroom implementation profiles (see Figure 2). Differences in LPTSs implementation were more prominent than in definitions of learning progression frameworks (Finding Set 1) or in descriptions of central LPTSs (Finding Set 2).

More specifically, we identified three common patterns in target teachers' implementation of LPTSs. One, across the five lessons videotaped, all four target teachers implemented two LPTSs: LPTS 4 on attending and responding to students' ideas and LPTSs 5 on authentic inquiry. Indeed, target teacher participants implemented LPTS 4 more often than any of the other LPTSs.   Two, none of the target teachers were found to implement LPTS 2 on planning instruction based on students' prior knowledge or LPTS 8 on citizenship-based decision-making. Three, there was clear alignment between three of the four strategies target teachers identified as central for movement along a progression and those strategies they implemented in their classroom. In their interviews, Ms. P, Mr. J, and Ms. E stated that LPTS 1 was important for movement along a progression; all three implemented LPTS 1 in the lessons we videotaped. In their interviews, all four teachers identified LPTS 4 and LPTS 5 as central to movement; all four implemented these strategies in the lessons observed as well.

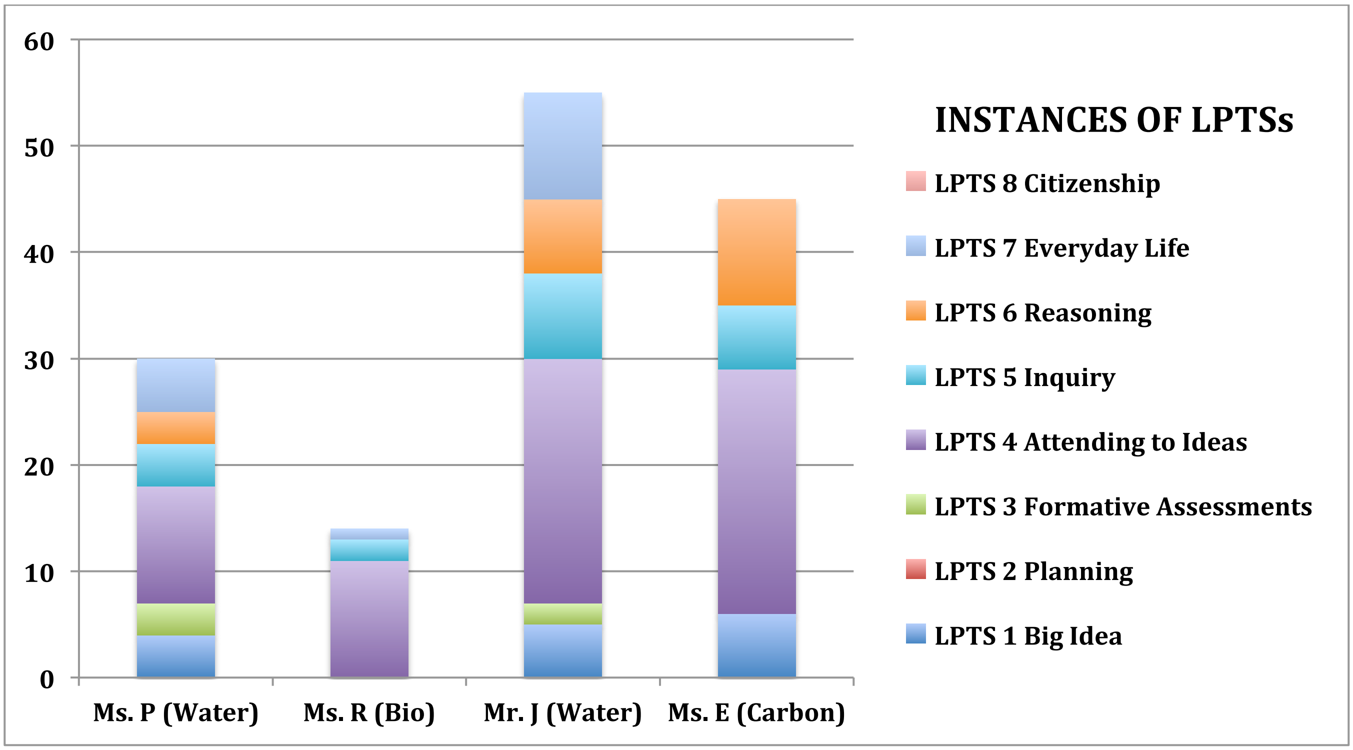

Figure 2. Number of LPTSs implemented in those lesson segments that included productive discussions in five videotaped lessons for each target teacher. Note that these are counts of LTPTSs – instances when LPTSs were implemented.

We also identified three distinct differences in target teachers' implementation. One, target teachers implemented different clusters of the eight LPTSs across the five lessons observed: Ms. P and Mr. J implemented six of the eight LPTSs; Ms. E, four of the eight; and Ms. R, three of the eight. This difference in the kinds of LPTSs observed may be linked, in part, to the TE implemented: Ms. P and Mr. J taught the Water Cycle TE, while Ms. E taught the Carbon Cycle TE, and Ms. R, the Biodiversity TE. Two, we found substantial differences across teachers in the total number of LPTSs implemented. More specifically, Ms. R implemented a total of 14 LPTSs across her five lessons as compared to Ms. P with 30 instances, Ms. E with 45 instances, and Mr. J with 55 instances. We note that the length of lessons does not appear related to this number: Ms. R's lessons were 90 minutes in length while Ms. E's lessons were only 45 minutes. Three, we identified several mismatches when comparing LPTSs teachers reported implementing versus LPTSs they actually included in their lessons. Some of these mismatches can be attributed to our decision to video record only five lessons of a TE, rather than the entire TE. For example, Ms. R stated that LPTS 8 on citizenship-based decision-making was central to her instruction; however, our coding of her lessons yielded no instances of this LPTS. Ms. R herself had noted that the lessons we observed did not include instances of this LPTS. Other mismatches are more difficult to explain. For example, in her interviews, Ms. P stated that she did not implement LPTS 6 on principle- and evidence-based reasoning. However, our coding of her lessons identified three instances of LPTS 6 implementation.

Finding Set 4: Professional Development Supports and Constraints

All teachers emphasized that they learned much from the professional development project. However, as with their implementation of LPTSs, the four target teachers varied in the number and cluster of LPTSs they identified as enhanced by the professional development effort (see Table 7 below.) For example, Ms. E noted that she had strengthened her understanding and implementation of LPTSs 3, 4, 5, 6, and 8 as a result of participating in Pathways. In contrast, Mr. J only noted that his understanding and use of LPTS 6 was greatly enhanced by his participation in the project.

Table 7
LPTSs Teachers Reported Most Influenced by Pathways PD Participation

Teacher	LPTS 1 Big Ideas	LPTS 2 Planning	LPTS 3 Formative Assessments	LPTS 4 Attending to Ideas	LPTS 5 Inquiry	LPTS 6 Reasoning	LPTS 7 Local Context	LPTS 8 Citizenship
Ms. P (Water Cycle)		X	X		X			
Ms. R (Biodiversity)				X	X			X
Mr. J (Water Cycle)						X		
Ms. E (Carbon Cycle)			X	X	X	X		X

Note: Boxes with Xs are those LPTSs identified by teachers as influenced by Pathways. LPTS columns that are shaded are those identified by teachers in Finding Set 2 as most central in moving students up a learning progression.

There was one clear commonality in teachers' reports of how the Pathways project strengthened their teaching: Three of the four target teacher participants, all but Mr. J, thought the Pathways project had helped to improve their implementation of LPTS 5 on inquiry investigations. For example, in response to a question about which two LPTSs were most influenced by Pathways, Ms. E stated:

> I'd say inquiry with authentic events and experiences. I mean definitely, because you're using data and you're looking at what data you get and then you're putting it up against what you thought. . . . So sometimes the data wasn't what it was supposed to be, but you're trying to make decisions based on data and then also based on the literacy, the readings. (Interview 4)

Four additional LPTSs – 3, 4, 6, and 8 – were each identified by two target teachers as strengthened by their participation in the Pathways PD effort. For example, two target teachers, Ms. P and Ms. E, emphasized that they learned a great deal about LPTS 3 on formative assessments. Ms. P stated: "Looking at the formative assessments and really looking at their answers and grouping the students helps me to see where they're starting at, kind of what they already understand, and then kind of where I need to take them." As a second example, two of the target teachers, Mr. J and Ms. E, noted that they learned much about LPTS 6 on principle- and evidence-based reasoning as a result of the PD. Mr. J noted:

> I gleaned a new appreciation for [LPTS] number 6, the principle-based reasoning, evidence-based argumentation [as a result of participating in this project]. And the verbiage I now use in my classroom is, "Provide an evidence-based conclusion." I used to say, "Write a conclusion and I need to know what you've got there and blah, blah, blah.". . . But [now I say], "Make a statement and support it with evidence." That's probably most significant. (Interview 4)

As with teachers' reports of LPTSs implementation versus their classroom instruction, there were several mismatches in looking across teachers' discussions of LPTSs implemented, their actual classroom practices, and the ways they thought they had benefited from the PD. As one example, of the four LPTSs teachers highlighted in Finding Set 2 as most crucial for moving students along a learning progression (LPTS 1, 4, 5, and 6), only one, LPTS 5, was identified by three target teachers as a strategy strengthened by their participation in the Pathways PD. One LPTS, LPTS 1 on big ideas, was not mentioned by any teacher as a strategy he or she learned much about from participation in Pathways. As a second example, some teachers thought they had learned a great deal about LPTSs not documented in their actual classroom practice. This was the case for both Ms. R (LPTS 8) and Ms. E (LPTS 3 and LPTS 8). Again, this might be explained by the difference in the number of lessons observed versus the length of the TE.

Discussion

Overall, we found reasonable alignment across our target teachers' views of learning progressions, their views and implementation of LPTSs, and their sense of how the professional development process supported their teaching. A clear example of such alignment is LPTS 5 on inquiry investigations. All four teachers stated that they implemented LPTS 5, thought this strategy instrumental for moving students along a progression, and regularly implemented LPTS

5 during the lessons observed. Three of the four teachers, all but Mr. J, also stated that the Pathways project enhanced the ways they engaged students in inquiry in their classrooms.

We also looked across our four sets of findings to identify mismatches in teachers' understanding and implementation – to identify ways to better support teachers in using learning progressions to inform their instruction. We discuss three mismatches across views and practices here. One mismatch we identified was in relation to LPTS 1 on big ideas. Three teachers, all but Ms. P, included key science constructs – constructs included in the TE they implemented – in their descriptions of learning progression frameworks. Three teachers, all but Ms. R, stated that they regularly implemented LPTS 1, thought that this strategy was essential for moving students along a progression, and were observed implementing this strategy in the lessons we recorded. However, none of our teacher participants stated that their engagement in the Pathways project supported their implementation of this strategy. Reasons for inconsistencies across views and implementation of LTPS 1 are not yet clear. We need to return to our data to investigate this strategy further.

As a second mismatch, target teachers placed uneven emphasis on LPTS 2, planning instruction based on their students' understanding. More specifically, all four teachers underscored the importance of supporting students in reaching a Level 4 understanding of concepts when describing learning progression frameworks. All four stated that they regularly implemented LPTS 2 in their instruction. Further, Ms. P noted that her implementation of this strategy was heavily influenced by her participation in the Pathways professional development. However, none of our target teachers thought this strategy important in moving students along a progression and none were found to implement this strategy in the lessons we observed.

We offer three possible explanations for this mismatch. One possible explanation is that our target teachers struggled to build their instruction from their students' understanding; this was found to be the case by Otero and Nathan (2008) and Harlow (2007). Indeed, in his discussion of LPTS 3 on formative assessment (see again Finding Set 2), Mr. J stated that he did not often use students' responses to "re-strategiz[e] for the next day." A second possible explanation is that our target teacher participants thought that the TE itself addressed this strategy. Ms. E made this point in Finding Set 2 above: She stated that she implemented LPTS 3 on formative assessments while she understood the curriculum to take care of LPTS 2. A third possible explanation is that teachers indeed implemented LPTS 2, but did so outside of actual classroom instruction. After all, the strategy is about the *planning* rather than teaching of lessons.

We as researchers were surprised by this uneven treatment of LPTS 2, because we understand LPTS 2 as tightly tied to LPTS 3 on formative assessments and LPTS 4 on attending and responding to students' ideas, and because we view this cluster of LTPSs 2, 3, and 4 as the core of what it means to teach from a learning progression frame. However, of these three strategies, our four target teachers viewed only LPTS 4 as important for movement along a progression and implemented only LPTS 3 (Ms. P and Mr. J) and LPTS 4 in the lessons recorded. Further, none of the target teachers identified all three as strengthened by their participation in Pathways: Ms. P identified LPTSs 2 and 3 as strengthened by her Pathways participation; Ms. E, LPTSs 3 and 4; Ms. R, LPTS 4; and Mr. J, none of the three. As such, LPTSs 2, 3, and 4 appears a cluster of strategies in need of more intensive professional development. Professional developers should work more closely with teachers to tease apart their understandings of LPTS 4 in relation to LPTS 2 and 3; to more deeply explore the interconnections across LPTSs 2, 3, and

4; and to help ensure a more even emphasis across these three strategies when trying to move students along a progression.

A third mismatch emerged in our examination of LPTS 6 on principle- and evidence-based reasoning. Three of our target teacher participants – Ms. R, Mr. J, Ms. E – stated that they regularly implemented LPTS 6 and thought it important for student movement up levels. However, Ms. R was not recorded implementing LPTS 6 while Ms. P was. For Ms. R, a possible explanation is that the investigations included in the Biodiversity TE did not provide repeated opportunities for students to engage in reasoning. For Ms. P, a possible explanation is that the dual focus of LPTS 6 encouraged the emergence of multiple definitions. LTPS 6 emphasizes both reasoning from principles, like the conservation of energy, and reasoning from evidence, like the mass of soil measured at the end of an investigation. This latter kind of reasoning is tightly connected to LPTS 5 on inquiry. Indeed, in their descriptions of LPTS 5, teachers pointed to the collection and examination of evidence as central to the inquiry process (see, as an example, Ms. R's descriptions of inquiry in Finding Set 2). As such, it is possible Ms. P did not think she implemented LPTS 6 because she equated it with reasoning from principles and understood reasoning from evidence to be part of LPTS 5.

In any case, as with LPTS 2, LPTS 6 is a strategy that could be more thoroughly examined in professional development efforts. With inquiry's long history in science education (Rutherford, 1964), it is likely teachers have some experience reasoning from evidence. However, the notion of principles and ways to effectively reason from them is a more recent emphasis. Indeed, using principles is tied to Level 4 of the learning progression frameworks developed by Pathways, a level contrasted with Level 3 *school science* accounts. As such, professional developers should devote more time and attention to engaging teachers in examining differences between Level 3 and Level 4 accounts and in providing teachers concrete ways to support their students in the unfamiliar practice of reasoning.

Concluding Thoughts

We note that our study includes a number of limitations. For example, we did not examine teachers' practice before they entered the Pathways project. We also neither collected data on teachers' implementation of a Pathways TE across multiple classes nor teachers' implementation of multiple TEs across the year of the study. Further, we did not examine those teachers in the Pathways project who were struggling to incorporate learning progression-based materials into their instruction.

That said, we think additional analyses of the data presented here will prove fruitful; we close with directions we intend to investigate further. For example, we intend to more carefully tease apart aspects of LPTS 4 on attending and responding to student ideas to determine (a) if and how teachers responded to and built on students' ideas once elicited and (b) how teachers understood and implemented LPTS 4 in relation to LPTSs 2 and 3. LPTS 6 also needs closer examination to determine (a) if teachers engaged their students in both principle- and evidence-based reasoning and (b) why they might favor one type of reasoning over the other. We also intend to compare our four target teachers to the rest of our 16 case study teacher participants. In doing so, we will be better able to determine if similarities and differences in the kinds and frequencies of LPTSs implemented are a result of individual teachers' preferences, differences in the structure and content of the three TEs, or strengths and limitations of the professional development process itself. Further, we intend to examine mis/matches between teachers' implementation of LPTSs and what their students learned (using focus group interviews and pre and post content test) as a result. These future inquiries should provide deeper insight into the mis/connections between learning progression frameworks and the kinds of instructional strategies that best promote student movement along these progressions, as well into the kinds of professional development efforts needed to support teachers in successfully using such frameworks to teach environmental science in reform-minded ways.

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